Direct Modulated Laser Signals

In prior art optical systems, lasers are directly and symmetrically modulated to produce a signal by increasing and decreasing the current to the laser. An increase and decrease pair is termed a "pulse." The pulse width of a symmetric input signal is equal to the bit-period. Figure 1 shows a typical optical communication system. A digital bit stream 110 is sent to a pulse shaper and driver circuit 120 driving a direct modulated laser diode 130. The generated light is coupled into an optical fiber 140. At the other end of the fiber, the light is detected by a detector 150. The current from the detector is amplified and filtered and finally made digital by the receiver electronics 160 which transmit a digital stream 170 which should be identical to the incoming bit stream 110.

Figure 2 illustrates a symmetric driver pulse. One pulse 200 is initiated at –100ps, and the current rises to 50 mA at time –50ps. Then, the pulse is terminated at time 0 and the current falls to the low level of 20 mA at time 50ps. Another pulse 250 is out of phase with the pulse 200 by 100ps. The area out of phase 240, is termed the "eye-opening," and the entire diagram where the pulse shapes overlap is termed an "eye-diagram." The eye-opening of the driver pulse is symmetrical. However, the output from a laser resulting from the symmetric driver pulse of Figure 2 exhibits ringing and chirping.

Figure 3 illustrates a laser output given the symmetric driver pulse of Figure 2. The output contains an overshoot 300 and a ringing undershoot 310 from the high level after the rise in current from the driver pulse. Additionally, the output contains an undershoot 320 of the low level following the fall in current from the driver pulse. The resulting eye 330 is asymmetrical and partly closed due to the ringing. In this particular example, there is a ringing effect when a preceding pulse is a zero resulting in a type of inter-symbol

interference. Additionally, a receiver attempting to detect the transmitted signal may misdetect the signal due to the undershoot. This results in errors in data transmission.

Figure 4 illustrates the chirp resulting form the driver pulse of Figure 2. The peak-to-peak value (the difference between the value at the high peak and the value at the low peak) is approximately 17 units.

Low-Pass Filtering

One prior art method of preventing ringing and inter-symbol interference is to low-pass filter the driving current. Thus, any signal power that would have been amplified by the peak in frequency response of the laser is avoided, hopefully reducing ringing. However, if the bitrate is close to the relaxation oscillation frequency, this method results in a loss of performance. Figure 5 illustrates a low-pass filtered symmetric driver pulse. Figure 6 illustrates the laser output given the symmetric driver pulse of Figure 5. The overshoot 600, ringing 610, and undershoot 620 are all reduced. However, the eye 630 is still asymmetrical and partially closed. Figure 7A illustrates the chirp resulting form the driver pulse of Figure 5. The chirp is reduced (having a peak-to-peak value of approximately 15 units), but still significant.

Pulse Propagation Over Single Mode Optical Fiber

Figure 7B illustrates pulse propagation over single mode optical fiber. The transmission speed is 10 Gbit/s. In pane 1 700, a symmetrical pulse is generated. Each pulse has a pulseshape with a linear slope for both the rising and falling edge. Both the rise and fall time are 20 ps. The pulses are used to drive a laser and the resulting signal is in pane 2 710. Pane 3 720 shows the signals after they have propagated over a single mode optical fiber 40

km in length. At the end of the fiber, the signal reaches a receiver. The receiver is modeled as a PIN-diode receiver with a 7.5 GHz 4th order Bessel filter. Pane 4 730 shows the filtered signal.